# COMPARATIVE EVALUATION OF FRONTAL OFFSET TESTS TO CONTROL SELF AND PARTNER PROTECTION

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## ABSTRACT

The present demand on self protection and insurance test is increasing the local strength and global force deformation of all cars. Unfortunately, the ratio is not the same, due to the different masses: The design of a large car makes it stiffer than a small one in order to compensate the mass. Furthermore, the current frontal offset test is more severe for heavy vehicles because of the specific barrier used. Due to this self protection trend, compatibility requirements are more and more difficult to achieve.

Moreover, it is yet required to improve light cars compartment's strength without increasing heavy cars' one and to limit vehicle front units' aggressiveness. In other words, it is necessary to assess the possibility to check and improve partner protection with regards to self-protection. To achieve this new requirement, an amendment of ECE R94 test procedure, based on PDB barrier, was proposed in order to check both parts of compatibility (structural interactions -partner- and compartment strength -self-), and is still being studied.

To validate and compare this approach with other offset procedures, many tests have been performed with different cars from European market (light and heavy, old and new generation, left and right hand drive) in different test configurations (current R94 at 56 km/h, possible future R94 at 60 km/h suggested by EEVC WG16 and PDB protocol at 60 km/h).

Based on the tests results, this paper describes in details:
- the comparison of different offset barrier tests
- the validation of PDB test protocol aiming to check self and partner protection
- the possibility to generate constant severity for all cars (same EES)
- the possibility to change the current frontal barrier
- the possibility to assess partner protection and self protection.

## INTRODUCTION

Current ODB barrier was developed fifteen years ago and adapted to car designs (geometry and force deformation) from 90's. Since then, introduction of regulation, ratings, insurance test and recently pedestrian have modified a lot car front design in terms of stiffness and geometry to achieve that requirements. The current barrier is becoming more and more obsolete regarding to new generations of vehicles.

With self protection offset test regulations and ratings, all cars offer equivalent behaviour against a fixed obstacle. These tests lead to stiffer front end and higher compartment strength. Solutions have been optimized against a rigid wall or soft obstacle but not in car to car configuration.

A new procedure must not compromise and decrease current self protection level. That is why the proposed procedure in this comparison checks compartment strength and structural interaction on the same time, without introducing additional tests as far as the compatibility demand depends on the vehicle size: Heavy vehicles need a better partner protection (structural interaction), and light vehicles need a better self protection (compartment strength) *(figure 1)*.

This paper deals with the development of a more comprehensive approach after having studied it different offset tests, aims to propose a test procedure and methodology as good as possible for a regulation approach in several steps towards the improvement of compatibility.

There are no effective proposed improvements unless they are applied by all manufacturers and for all passenger cars. The only way to reach that target is to define and then apply a new regulation.
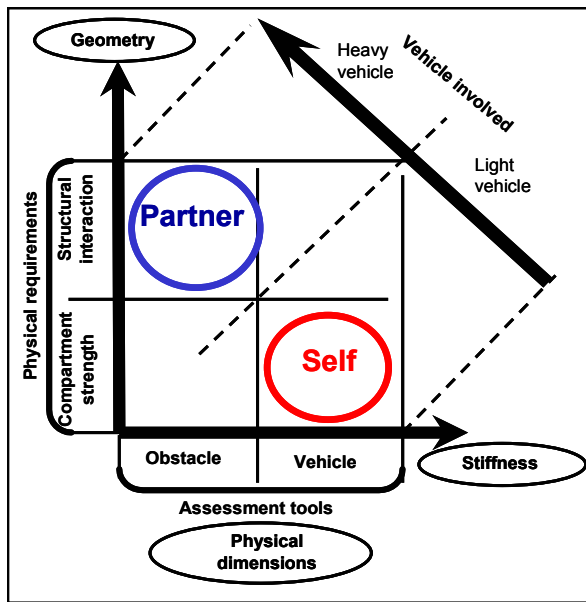
Figure 1: Compatibility summary

## FRONTAL TEST PROCEDURE

Three main offset test procedure have been investigated. The current ECE R94, the EEVC WG 16 proposal for assessing self protection and the PDB protocol that takes into account three new parameters to be in line with compatibility requirements:

- partner protection without decreasing self protection against rigid obstacle,
- different vehicle mass range,
- compatibility requirements (self and partner)

### Current test procedure

This procedure is fully known all around the world, and most of countries apply this test procedure as a regulation and / or a rating.



Regulation ECE R94:

- Test Speed: 56 km/h
- Overlap: 40 %
- Barrier: current ODB

Figure 2: ECE R94 test configuration (called R94)

### EEVC WG16 test procedure proposal

This procedure has been proposed by WG16 to improve self protection against rigid obstacle but could be dangerous for compatibility in terms of self and partner protection.



Derivate from ECE 94:

- **Test Speed: 60 km/h**
- Overlap: 40 %
- Barrier: current ODB

Figure 3: EEVC WG16 test configuration (called R94-60)

### PDB test procedure – French proposal

Details of the procedure are fully explained in document "PDB Test Procedure V2-2" published in the EEVC WG15 web site. Test configuration is not so far from current regulation but some essential changes must be included (especially the barrier).



Derivate from PDB test:

- **Test speed: 60 km/h**
- **Overlap: 50 %**
- **Barrier: PDB**

Figure 4: PDB test configuration (called PDB 60)

Compatibility is a mix between self protection and partner protection and can not be separate for investigation because both act simultaneously.
Compartment strength is an answer for the first one, homogeneous front end is an answer for the second to improve structural interaction.

### Why is a new barrier necessary?

Instability



Figure 5: Current ODB barrier instability tested with the same car. Test is not reproducible.

The current barrier was designed many years ago for the previous vehicles generation, weaker than the new one. Since this time, vehicles were reinforced and became stiffer. The stiffer front end leads to unstable

behavior of the barrier that creates serious problems in the design of vehicles. Sometimes barrier absorbs energy, sometimes not.

Bottoming out

Each new generation of vehicles bottoms out the barrier (*Figure 6*) that leads same amount of energy absorbed by the barrier.
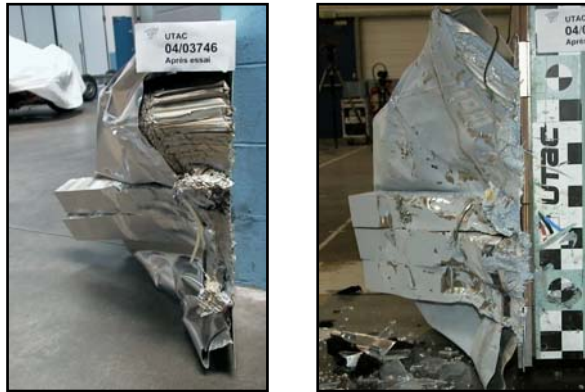


***Figure 6: ODB barrier bottoming out: same amount of energy, structures collapse against rigid wall***

The energy absorbed by the barrier does not depend on the vehicle mass. Severity for the vehicle structure rises up with the mass. *Figure 7* clearly shows this unequal energy distribution. The fraction of energy absorbed in the barrier is roughly the same regardless of the car mass resulting in a higher fraction of energy to be absorbed by the large vehicle than by the small one. For a light car, energy in the barrier represents 40% of the total kinetic energy but only 10% for a heavy one.
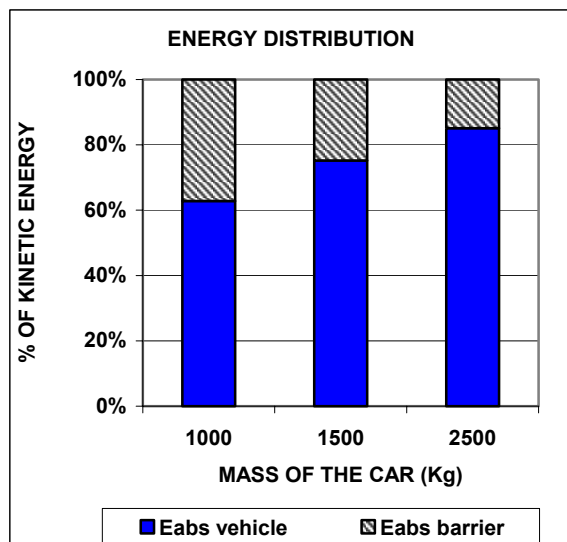


***Figure 7: Severity situation with current barrier, percentages of kinetic energy absorbed.***

So in order to reach the same level of self-protection, design against deformable barrier with bottoming out

results directly in even stiffer heavy cars because this test is more severe than for small ones *(Figure 8)*.The result is that heavy cars cannot be made compatible, in term of stiffness, with small ones
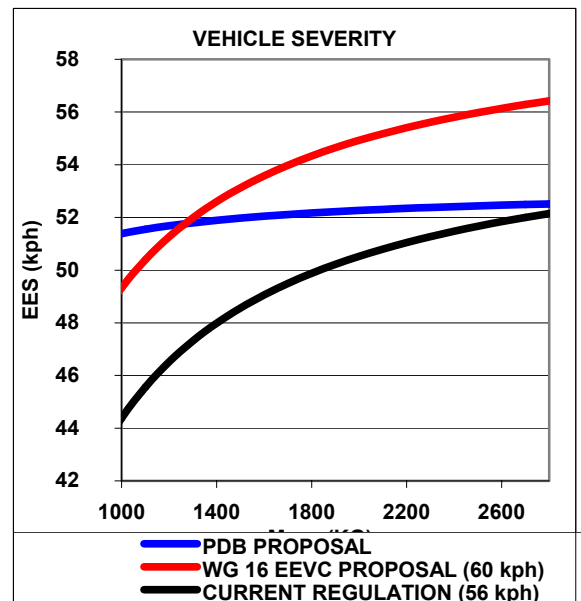


***Figure 8: Theoretical Test severity depends on the vehicle mass. Need to harmonize this phenomenon.***

Current ODB barrier is not yet adapted to the new generation of cars. It is urgent to harmonize severity for vehicle range mass to reach self protection compatibility requirements and avoid inhomogeneous fleet.

**Barrier used**

Following test procedures, the PDB barrier was introduced in the comparison. Its high force level and high energy absorption capacity is supposed to resolve the question of bottoming out *(Figure 9)*.
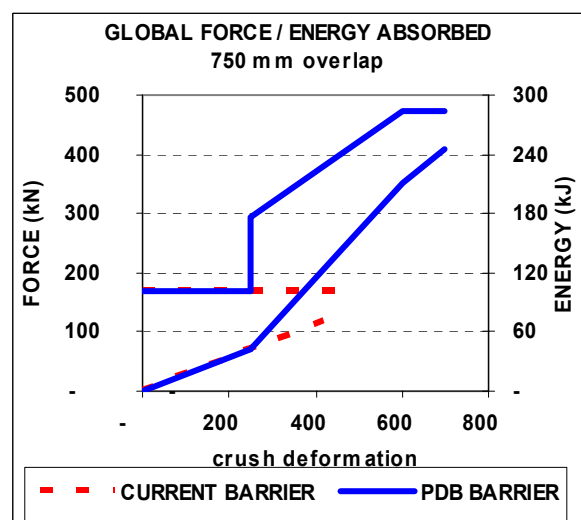


***Figure 9: Force and energy capacity comparison for a same overlap***

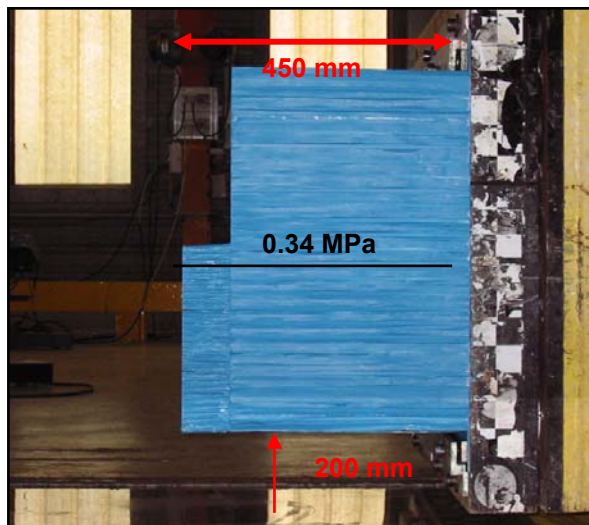**Current ODB barrier**



*Figure 10: Current ODB barrier - Side view, dimension, position and stiffness.*
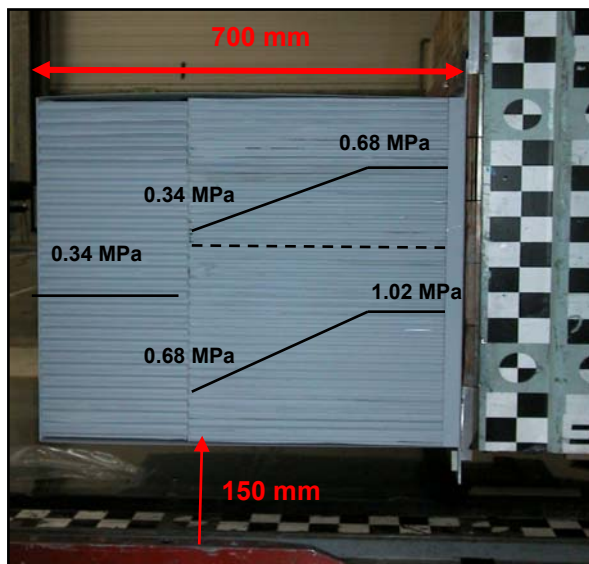
**PDB barrier**



*Figure 11: PDB Side view. Dimensions, position and stiffness.*

PDB is now well known *(Figure 11)*. It is a progressive increase in stiffness in the depth, and two height dependant stiffnesses, which contribute to its name: PDB as Progressive Deformable Barrier. Furthermore car force distribution in height should be represented; the lower front load path is usually stronger than the upper one. Its dimensions and stiffness make the bottoming-out phenomenon very unlikely because force and energy capacity are equal to four time the current barrier.

**Why a new test speed is needed?**

To answer the question of improving compartment strength of the light car, it was necessary to increase the test speed to reach compartment deformation. 60 km/h seams reasonable. Furthermore, this test speed was proposed by EEVC - WG16. However, this increasing speed must be accompanied by a barrier change to reach compatibility requirements to avoid stiffer and stiffer heavy vehicle compartment.

**Why a new overlap is needed?**

Checking half of the front end is needed for partner protection assessment in the future. Secondly, overlap is closer to real world accident data and car to car test configuration. Finally, combined with stiffer barrier it generates higher acceleration pulse that we will develop in a next chapter.

**Vehicle type investigated**

To demonstrate previous approach, 16 tests were performed with different cars, test configurations and driving position.
Car is tested in regulation approach that means in the worst case: heaviest mass, all options and largest engine. Four cars from French manufacturers have been selected:
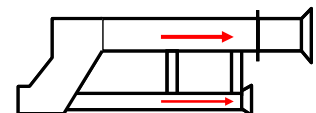
Super Mini Car 1
SMC1 -1151 Kg
New generation- with stiff front single load path and high compartment strength.
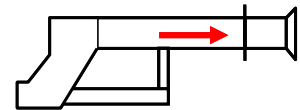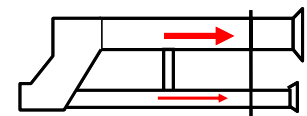
Super Mini Car 2
SMC2 -1130 Kg-
Old generation- with weak front double load paths and weak compartment strength
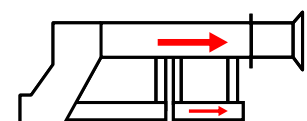
Family Car 1
FC1-1747Kg-
Last generation- with stiff front double load paths with advanced lower load paths and high compartment strength

Family Car 2
FC2-1677 Kg-
New generation- with stiff single load path with added lower load path and high compartment strength.

**Test configurations investigated**

Three test configurations have been investigated explained before:
- ECE R94 with current ODB barrier
- Current ODB barrier at 60 km/h
- PDB barrier protocol at 60 km/h

Each vehicle was tested in Left Hand Drive and Right Hand Drive.

**TEST RESULTS**

**Test severity**

One of the most important in this study was to check the test severity for each vehicle in terms of energy absorption. *Figure 12* represents the amount of energy absorbed by the current ODB barrier and the PDB. The higher absorption potential of the PDB is clearly shown.
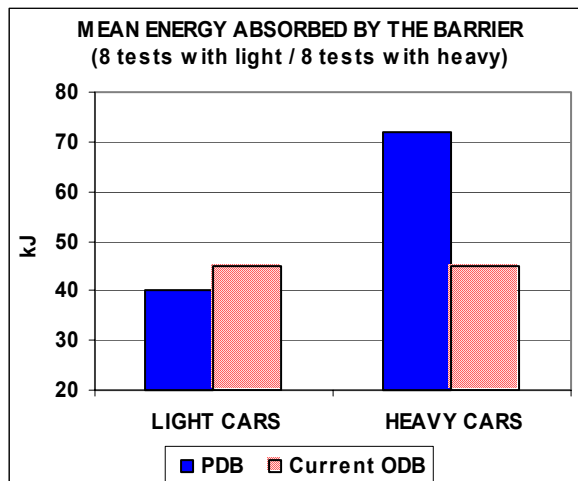


*Figure 12: Energy absorbed by the barrier*

This leads in a non constant energy absorbed by the vehicle depending on the force deformation.
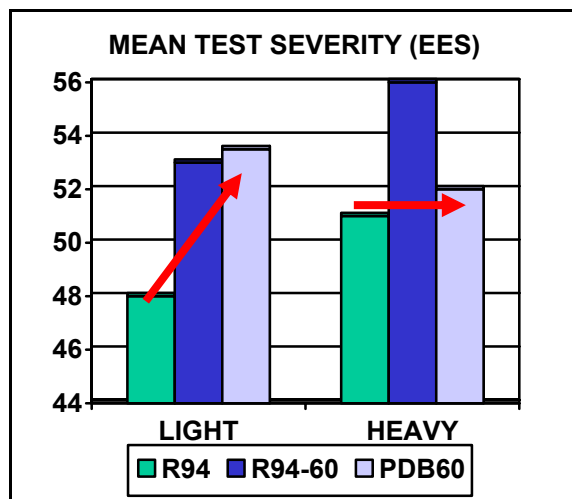


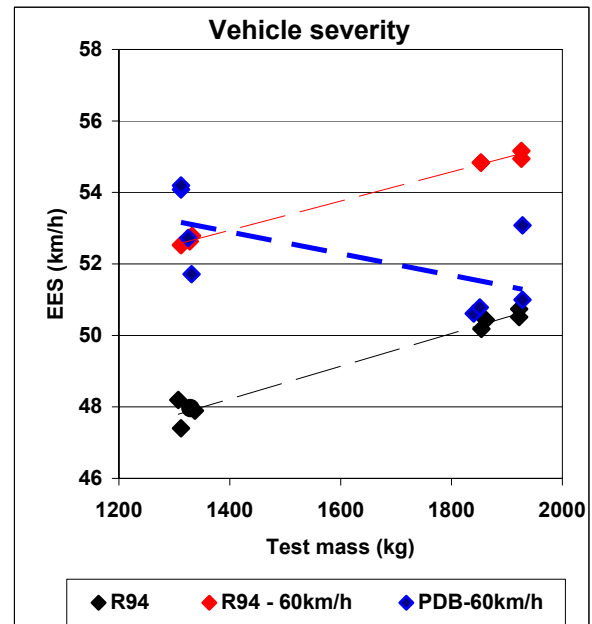*Figure 13: Mean test severity in terms of EES*



*Figure 14: Test severity observed vs Mass*

Test confirmed theoretical assumptions. When considering the PDB barrier test, severity in terms of energy absorbed for light cars increased and became close to EEVC WG 16 proposal *(Figure 13 / 14)*. On the opposite, severity for heavy vehicles stays remained close to current R94 without being below. Current self protection severity is not compromised and light vehicle compartment can be investigated.

**Self protection analysis**

Car design for frontal crash must limit passenger compartment intrusion and generate acceptable deceleration from the occupant point of view.
Higher acceleration pulse combine with higher intrusion level allows getting closer to real life accident where both parameters are responsible for fatal injuries and injured.

**Passenger compartment intrusion**

Car to car tests conducted in the past confirm that the front-end stiffness and compartment strength have an influence on compatibility.
Compartment intrusion was shown as the most important parameters in car to car head on collision, so this parameter must be put under control. This parameter is directly linked to the force generated by the compartment.
Compartment intrusions *(figure 15)* are going in the same way than EES severity. Light vehicles suffer more in PDB test configuration, especially for the old generation. Severity for heavy vehicles stays constant. Compartment strength principle is validated. Light cars are overloaded without punishing heavy ones.
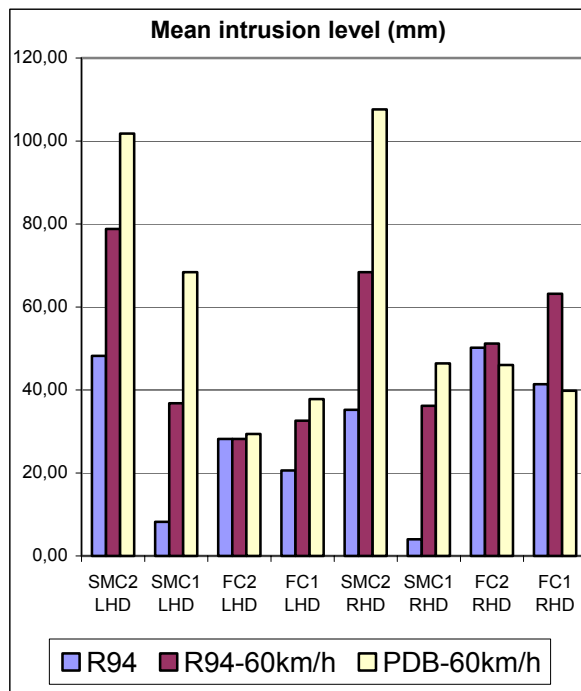
*Figure 15: Intrusion level comparison*

### Passenger compartment acceleration

Theoretical approach is also confirmed regarding acceleration pulse *(Figure 16)*. Stiffness of the PDB combined with protocol overlap generate higher acceleration pulse (without reaching the full width test pulse). The displacement distance with PDB is lower than ODB barrier that leads to higher deceleration pulse.
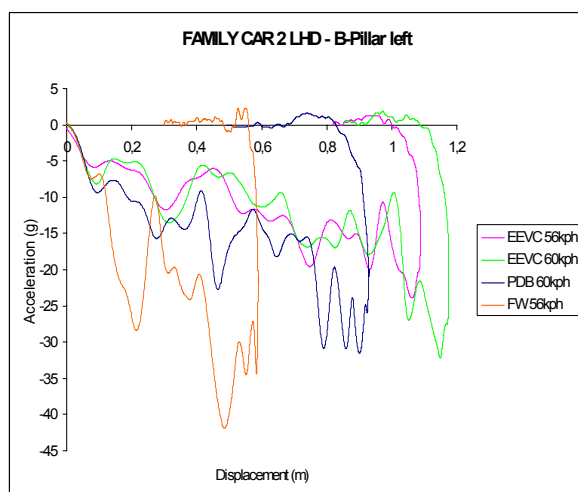


*Figure 16: Acceleration pulses corresponding to a family car.*

The mean acceleration information (g = delta V / t) is higher 20 % than current R94 *(figure 17)*. Time duration depends on stiffness and mass. When the stiffness increases, the time duration decreases, the mass stays the same.
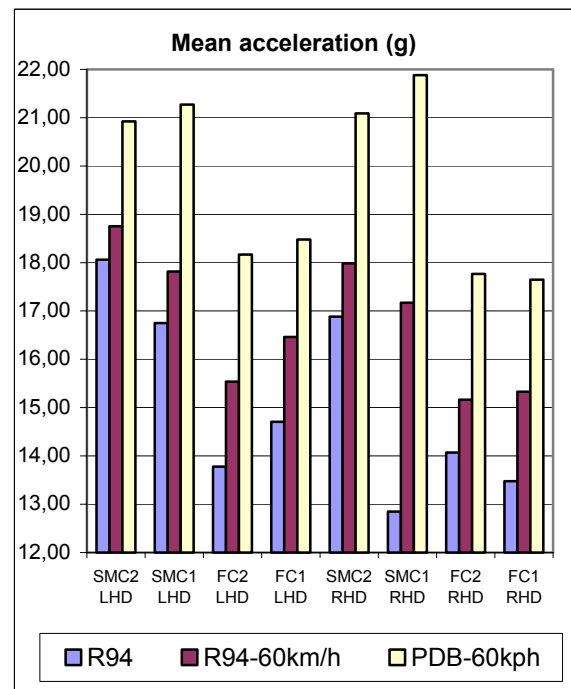


*Figure 17: Acceleration level comparison*

We have seen that PDB provides lower acceleration pulse than full width; however that test is able to generate in the same time acceleration and intrusion both parameters responsible for fatal and serious injuries *(figure 18)*. This combination makes this test closer to real life accident.
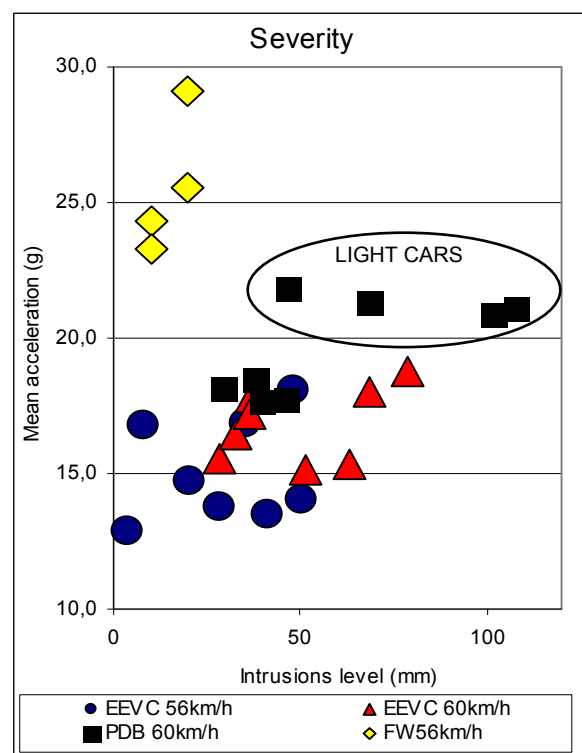


*Figure 18: combination of intrusion and acceleration in the same time.*

Delannoy Pg. 6.

### Dummy criteria

Even if dummies are not good tools to give an evaluation of severity due to dispersion, these one seams to confirm what we have seen before. PDB test can be severe for some categories of vehicles, especially old generations of light cars (that is going to disappear in a near future). A rating color classification has been used to illustrate the higher severity for a light car from the old generation *a*nd a family car from the new generation *(Figure 19)*.
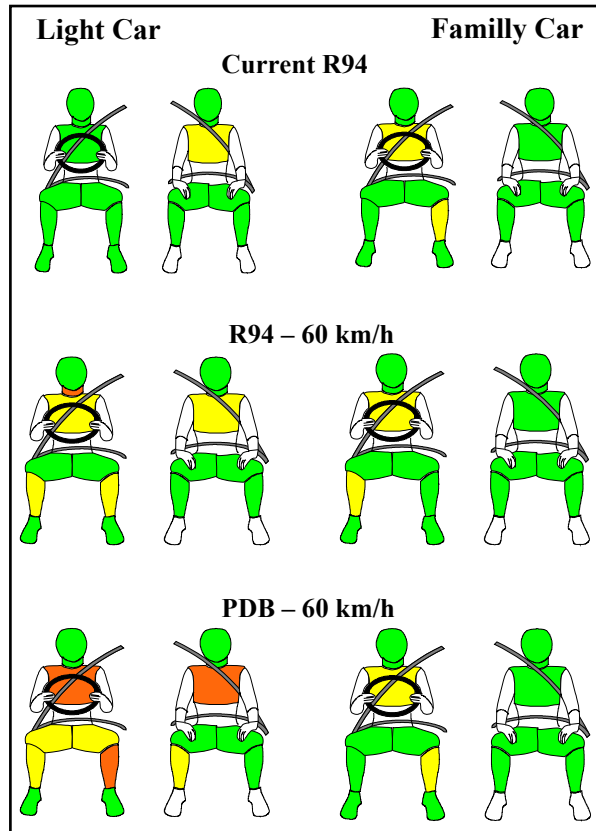


*Figure 19: Dummies criteria for different offset test configurations.*

However, recent generation of vehicles with high compartment strength, fitted with high performance restraint system is not sensible to this increasing severity (full data are available).

### Partner protection analysis

In order to take advantage of all the potential for energy absorption of both cars, their structure must interact correctly. Limiting energy deficiency is now something that is generally accepted and leads to better structural interaction.

### Barrier and front unit deformation comparison

Even if it is not the first priority, PDB definition allows checking and in the future assessing partner protection. In addition to test all vehicles at a more or less constant equivalent energy speed (EES), PDB is

the ability to check the front unit aggressiveness. Bottoming out of the barrier face in case of stiffer front-ends of the larger vehicles is avoided as it is proved by tests performed *(figure 21)*.



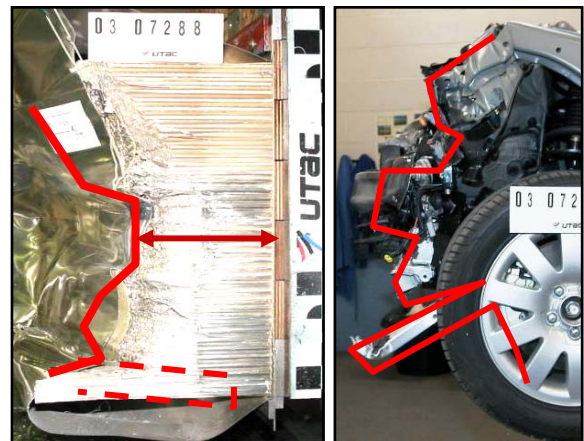*Figure 20: front deformation of 2000 kg family vehicle against current ODB barrier*



*Figure 21: front deformation of the same family vehicle against PDB barrier*

To reach the desirable intrusion level, the engine compartment has to absorb a certain amount of energy. Usually this is achieved through different load paths which absorb energy and transmit the load from the front to the occupant compartment. These load paths are designed and tuned against two types of obstacles: full width rigid barrier or soft deformable barrier. So far tests carried out on deformable barrier showed bottoming out phenomenon. This means that the front end design is not controlled by the barrier stiffness because the structure collapses with the help of the rigid wall behind the barrier. In all cases the obstacle is far from representing a car front unit. That's why structural behaviour in car to car accidents is different. Barrier shape is completely different; the current barrier deformation does not contribute to improve partner protection. No chance to detect front unit homogeneity, at the end of crash, all vehicle

deformations are completely flat smoothed by the rigid wall (Figure 20 and Figure 22).

By which, front unit deformation resulting from PDB test is fully different. Bottoming out of the barrier face in case of stiffer front-ends of the larger vehicles is avoided. As it is proved by tests performed *(figure 21 and figure 23)*.
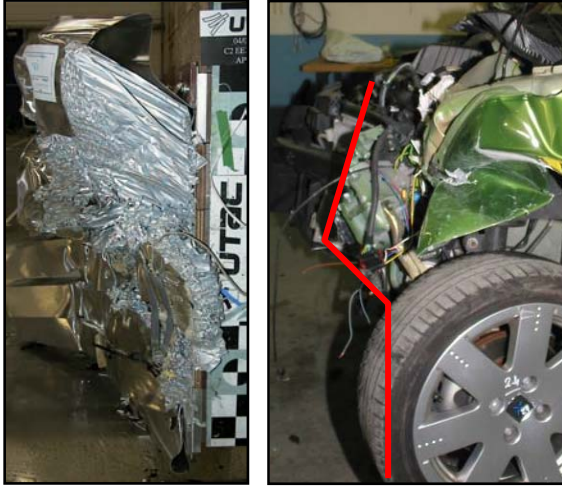


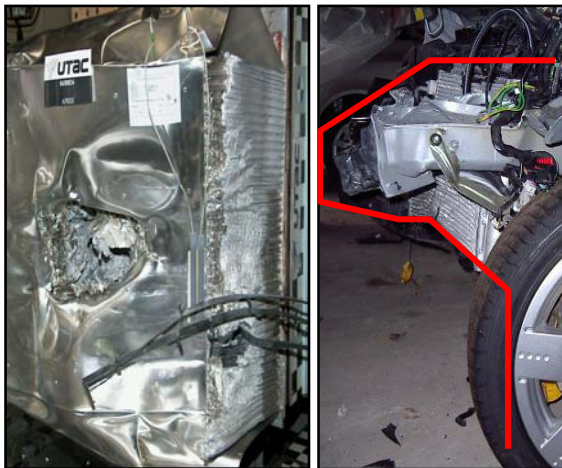*Figure 22: front deformation against current ODB barrier of a super mini car*



*Figure 23: front deformation of the same super mini car against PDB barrier*

**Barrier analysis**

PDB test procedure puts under control the energy absorbed by vehicle, the barrier is supposed to represent the vehicle we want to protect.

In the opposite of current offset test procedures proposed for compatibility assessment: car impact against weak deformable obstacle (with bottoming out phenomenon), the barrier deformation can be investigated. As we have seen before, against a rigid wall or soft barrier, the various load paths are not working the same way as they do in car to car interaction *(figure 20 / 21- figure 22 / 23)*. The deformation process is at displacement dependant, whereas in car to car, the deformation is at pressure

dependant. A car impact on a rigid wall might seem more simple: unfortunately it is not representative of a car front block and far from real world accident observations.

Current barrier can not be investigated, only the front face of the PDB barrier is able to give vehicle front end information (force and geometry).

**Super Mini Car 2** *(Figure 24)*:
Weak and multiple load paths car do not penetrate the barrier. Forces are well distributed. Front deformation is homogeneous. Unfortunately, this soft stiffness design tends to disappear with self protection and reparability requirements.
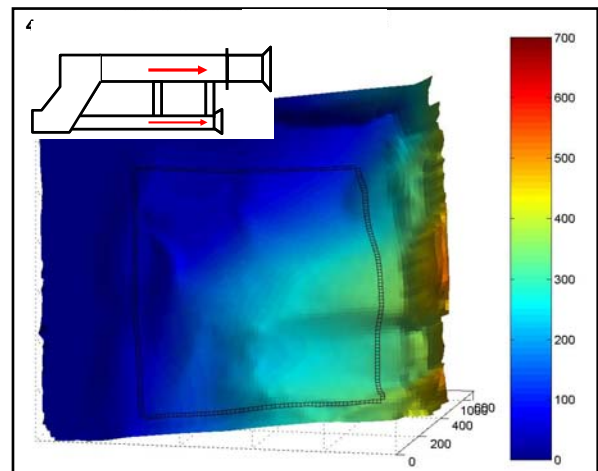


*Figure 24: PDB deformation corresponding to the weak super mini car (SMC2) with lower load path*

**Super Mini Car 1** *(Figure 25)*:
Stiff longitudinal with weak cross beam penetrates the barrier. Forces are badly distributed. Cross member is not able to spread the force coming from the longitudinal. The surface in front of the load path is not in line with its stiffness. Deformation is unhomogeneous.
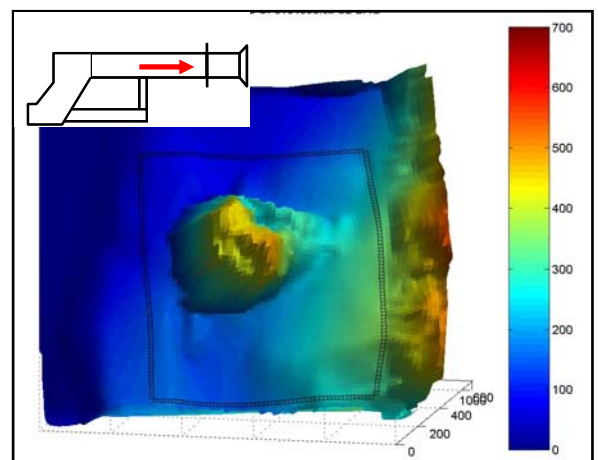


*Figure 25: PDB deformation corresponding to the stiff super mini car (SMC1) without lower load path.*

**Family Car 2 (Figure 26)**:

Forces generated by stiff longitudinal are well distributed by the cross beam. However, this one over crushed the barrier compare with lower load path. Front deformation is homogeneous in front of the cross beam, but quite inhomogeneous in height.
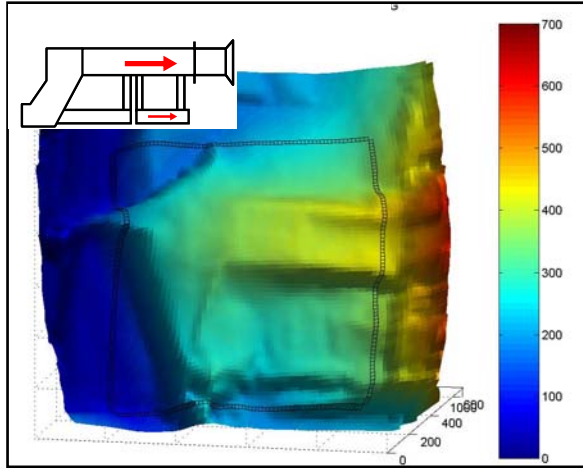


*Figure 26: PDB deformation corresponding to the stiff family car (FC2) without advanced lower load path.*

**Family Car 1 (Figure 27)**:

High forces generated by longitudinal and subframe are well distributed on a large surface. No over crushed between upper and lower load paths. Deformation is homogeneous.
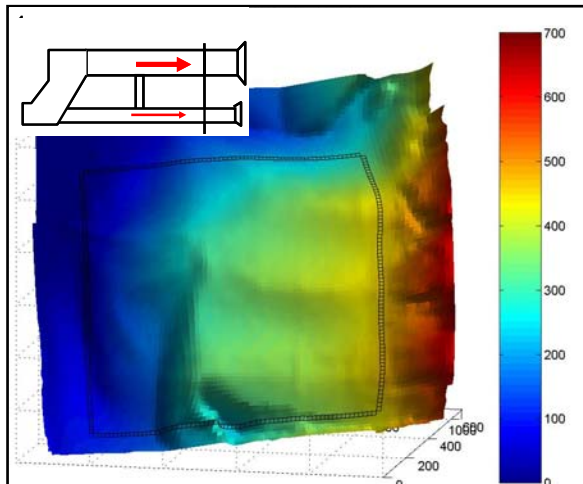


*Figure 27: PDB deformation corresponding to the stiff family car (FC1) with advanced lower load path.*

The PDB barrier is able to detect local stiffness but also transversal and horizontal links among load paths. The barrier records front cross member, lower cradle subframe, pendants linking position and stiffness that improve vehicles compatibility. That's why, assessment proposed for the future will be based on deformation because information is inside.

**POSSIBLE ASSESSMENTS**

As we have seen before, the test protocol allows checking simultaneously the two parts of compatibility:

- self protection coming from vehicle analysis and dummy criteria
- partner protection coming from barrier deformation

After having defining the test procedure and the obstacle, a set of relevant criteria have to be fixed in order to keep under control front end and passenger compartment design over the market production.

**Self protection**

Today, self protection assessment is very well known. According to current ECE R94 and EEVC WG16 proposal, assessment would be based on dummies criteria and intrusion measurements such as dashboard, firewall and A pillar *(Figure 28)*.



*Figure 28: Assessment comes from dummy readings and intrusion*

**Partner protection**

The problem today is to find common criteria that will be representative of this phenomenon in order to put this item under control.

In term of design, one way to achieve structural interaction is to offer a front surface which is homogeneous in stiffness over a surface which is large enough. To illustrate this point, we have to imagine that we put a rigid plane between both cars. The concept of the wall is to have a homogenous stiffness over a large surface. To achieve this result, the stiffness on the front block must be distributed along multiple load paths. Having this is not enough, as they cannot ensure that the stiffness is homogeneously spread over the front surface.

The PDB deformation already showed its capacity to verify the behaviour of new vehicles in regard to the partner protection targets. There is an assessment

(PPAD) calculated by PDB software that can be loaded from the EEVC WG15 Website. However, this assessment is not yet ready to be introduced as partner protection criteria.

**Investigation area**

Investigation area is different from the recorded area represented by the total front PDB surface.
According to geometrical measurements of European fleet and essential load paths needed for good structural interaction (upper rail, cross beam and subframe), the investigation area was fixed between 200 mm and 700 mm ground clearance in height (Z axis) *(Figure 29 / 30)*.
In Y axis, the area depends on the width of the vehicle. To avoid boundary effects, 100 mm margin in left and 150 mm in right are applied for LHD, the opposite for RHD.
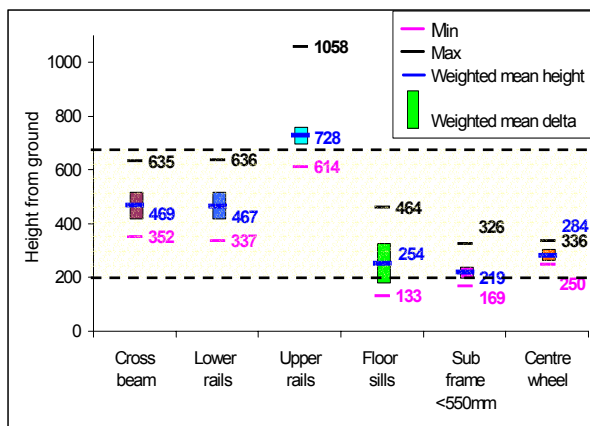


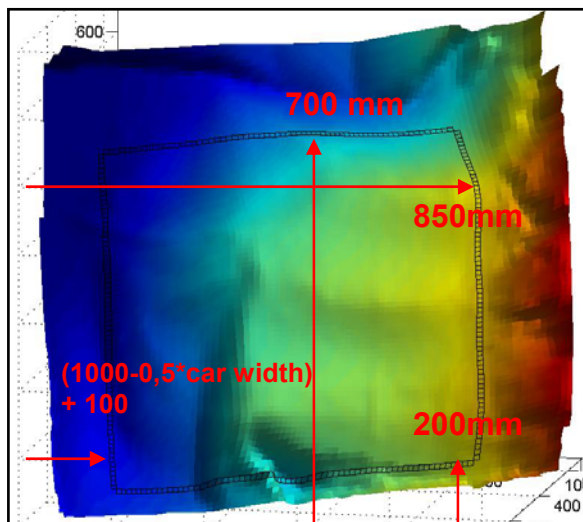*Figure 29: Geometrical data (ground clearance) of 70 % of the European fleet*



*Figure 30: Investigation area.*

**Possible basic criteria (mid term)**

The current formula given by the PDB Software V1.0 that we have seen before is little bit difficult and mix

geometry effects as well as stiffness effects without dissociating both. That's why; we propose a comprehensive approach, separating geometry from stiffness.



‑ ‑ ‑ ‑ ‑     BARRIER BEFORE
——————     BARRIER AFTER
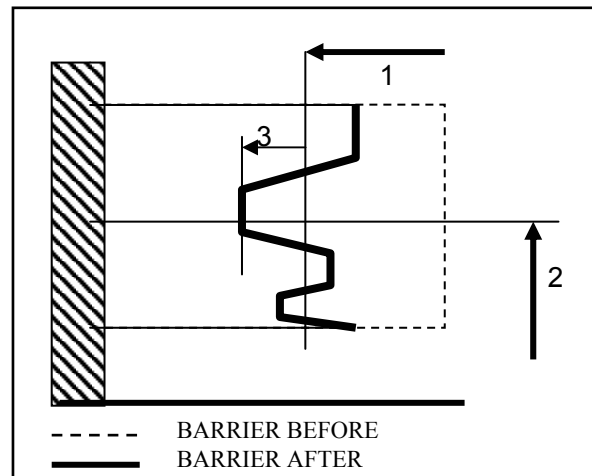
1-  ADOD: Average Depth Of Deformation
2-  AHOD: Average Height Of Deformation
3-  HP: Homogeneity Parameter

*Figure 31: possible partner protection parameters*

Results show that AHOD are less sensible to the tested car and similar to AHOF approach. ADOD is link to the front stiffness of the car and rise up with the mass. HP is supposed to detect local penetration in the front barrier face that indicates bad homogeneity. First results seem to confirm that using average could be the wrong direction.
However, it is too early to introduce a partner protection assessment. Further working is required before proposing a set of criteria.
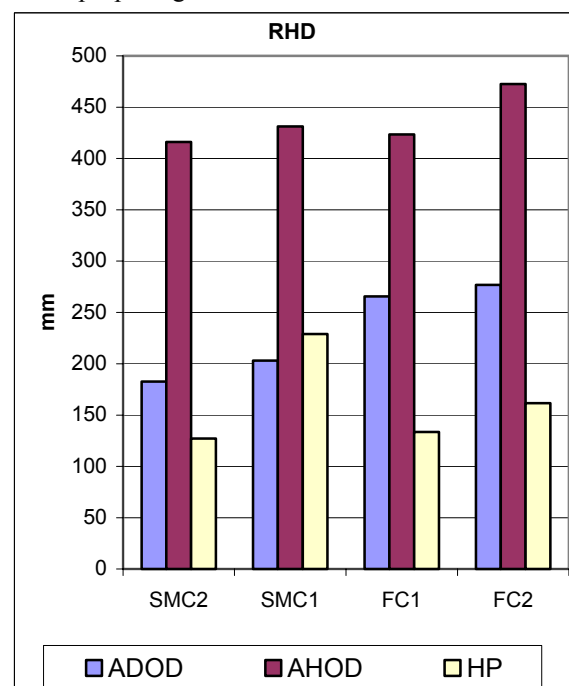


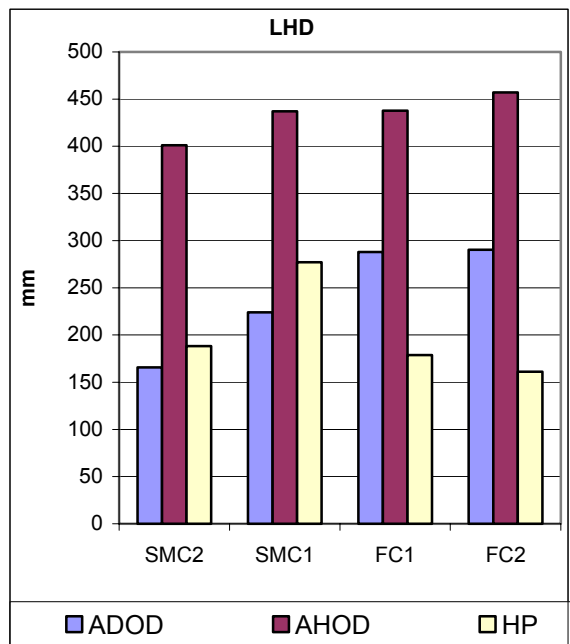*Figure 32: AHOD, ADOD and HP in Right Hand Drive.*

**LHD**

*Figure 33: AHOD, ADOD and HP in Left Hand Drive.*

Left hand drive and Right hand Drive results are very close; the PDB face deformation is not so much influenced by the driving position and tested side, in other words, by the gear box and engine position.

**Future working**

These tests will be accompanied with a car-to-car test in order to validate the PDB deformation.
Due to the necessity of self-protection and the wide range of vehicle's size, mass and stiffness, we have to define and fix a limit for compatible design.

**POSSIBLE STEPS FOR PROGRESSIVE COMPATIBILITY INTRODUCTION (Figure 34)**

**First step solution- short term- : Improving and harmonize Self Protection level**

As a first step, the French proposal is to replace the current ODB barrier by the PDB one in regulation. The first effect of the progressive barrier is the ability to test all vehicles at a more or less constant equivalent energy speed (EES). In this first phase, assessment remains focused on self-protection. PDB barrier introduction will be able to improve self protection of light vehicles (overloaded) without increasing heavy ones due to energy capacity absorption. The test severity is in line with the speed proposed by the EEVC WG16, higher than the current European regulation (56kph) and fixed for all cars

Self protection is already assessed for a long time from dummy criteria. The proposal suggests adding intrusion level investigation.
Dummies criteria limits are the same than the current ECE R94 and integrity of the passenger compartment could be assess with the help of intrusion level in different part of the front compartment.
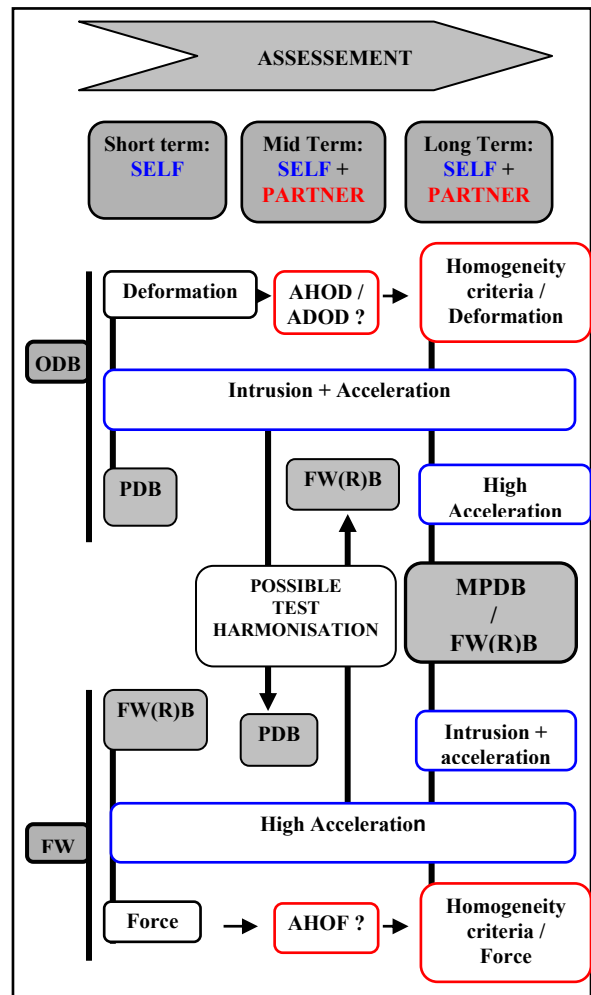


*Figure 34: Possible steps towards compatibility harmonisation*

**Second step solution -mid term- : Partner protection introduction**

We hope that partner protection will be ready at this time. All criteria and investigations will be based on the barrier deformation. PDB barrier is able to detect local stiffness but also transversal and horizontal links among load paths. It looks like car to car accident or test analysis, except that in this case, the barrier deformation is investigated instead of the car's. An aggressive vehicle would be identified by large and non homogeneous deformation.
Furthermore, this proposal could generate higher deceleration pulse combined with higher intrusion. However, further researches are necessary.

**Third step proposal- long term- : introducing Mobile PDB**

To be closer to real life accident, the PDB could be fixed on a mobile trolley as Australia investigated three years ago. A quick energetically approach clearly shows than this test due to conservation of momentum associated to different energy absorbed in the barrier allows to progressively switch from a light car overload to a heavy car partner protection test. However and before proposing this test as a regulation, we have to investigate it.
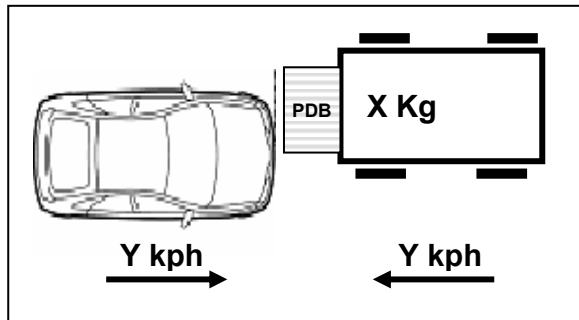


*Figure 35: Possible long term proposal*

**CONCLUSION**

After having compared the different offset test proposed, considered current and future generation of cars in Left Hand Drive and Right Hand Drive, it appears to us that test with current barrier is not adapted to new compatibility requirements.
It conducts to an inhomogeneous fleet due to non adapted deformable element. Furthermore, rising up test speed without changing deformable element could become very dangerous for compatibility issue and does not represent an answer for heavy / light vehicle compartment strength harmonisation. Furthermore, current barrier deformation does not allow investigating partner protection.

Harmonisation of offset test severity is considered by several passive safety experts as the main priority, the most effective way and probably the first step towards compatibility. Unfortunately, as we have seen before, unstable obstacle, bad reproducibility and bottoming out make tests with current barrier far from this objective. That's why, the replacement of the current deformable barrier by the PDB one is becoming the first priority. On the same time, checking light car compartment strength is proposed; test speed would be fixed at 60 km/h corresponding to WG16 suggestion.
This proposal would be able to check both self and partner protection and easy to introduce as a regulation.

However, in a first step, only self protection will be assessed. It is too early to introduce partner protection assessment, criteria are not yet ready. Further investigations are needed; several international task forces are working in that direction.
However, aggressiveness assessment is achievable from the barrier deformation. The studies in progress confirm that statement. The concept, close to real life car to car collision clearly shows the capacity of the front unit to be aggressive or not. A basic assessment could be introduced in a second step.

The development of future vehicles with respect to these targets would result in a compatible fleet. Moreover, considering the time taken to renew all the vehicles, it is necessary to propose measures that change too often to avoid rupture in the fleet.
To conclude, even if the PDB offset test doesn't generate high deceleration pulse, test procedure is fully representative of real world accident because it combines acceleration and intrusion and would become a restraint-system dimensioning test associated with intrusion.

**REFERENCE**

1    VC Compat (Car and trucks leg) activities

2.   EEVC / WG 15 activities

3.   EEVC / WG16 activities

4.   IHRA frontal group activities

5.   PDBsetupV10 application can be loaded from the EEVC WG15 Website (www.eevc.org)

6.   PDB test procedure V2-2 can be loaded from the EEVC WG15 website (www.eevc.org)